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Real-time supply chain predictive metrics

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ABSTRACT

Supply chains drive the production world. Virtually all products use a supply chain to produce them and they can determine the success of companies using them. The ability to manage supply chains is currently a mix of relationship management and science, combining personal and company relationships with data analysis.

The increased dependency on supply chains has increased the need to develop and use predictive real-time metrics to manage supply chain risk, measure suppliers and drive performance. Current metrics used are reactive and stagnant in nature. Real-time metrics will allow supply chain professionals to better manage risk. Current management techniques include fire fighting techniques, with limited data analysis or future prediction capabilities. Combining the current metric packages with real-time metrics can create a more transparent supply chain with prediction capabilities and increased risk mitigation opportunities. This dissertation describes why a real-time predictive metric package and model is needed, shows how to create one, provides an analysis on the use of real-time predictive metrics and correlates metrics to performance, and provides future work areas for predictive metrics.

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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

1. INTRODUCTION

Increased control is needed as supply chain performance and customer needs change over time (Gunasekaran, 2004). A supplier's ability to produce a product can change dramatically overnight. Due to numerous reasons including employee turnover, financial stability issues, mergers and acquisitions, programs around the world ramping up and down, capacity changes, changing relationships in the supply chain, and technology changes. Many companies have not succeeded in maximizing their supply chain's potential because they have failed to develop the performance measures and metrics to fully integrate their supply chain (Gunasekaran, 2006). Further, supply chain professionals are not happy with the current metric packages being used today due to their lack of insight (Trent, 2010). Increased control is needed to manage the risk of the supply chain for a customer, and the management of these supply chain changes and risks can determine the future of a company. A real-time metric package can assist by impacting delivery, cost to a customer, and perceived and real value to the end item user who buys the product from the customer of the supply chain with the belief that the supply chain used is being actively managed by the customer in a real-time manner.

1.1 MOTIVATION

Changing and competitive environments, increased use of supply chains, suppliers working for multiple customers and other suppliers in the same industry, and customer expectations have created the need for a more transparent and effective supply chain. Most current metric packages with suppliers are stagnant in nature and lead to fire fighting. Current metric packages do add value by providing a piece of supply chain transparency and should continue to be used; however, they do not paint the entire picture. Current metric packages do not completely take into account the changing supply chain environments. With an increase in the amount of outscoring, the need for a new metric package to manage larger and more complex supply chains is needed. Suppliers are working for multiple customers more than in the past and, therefore, their relationships change with each customer over time. In the past, many suppliers were focused on one customer and would do anything to please that customer. Past reactive metric packages were adequate when the relationship with a supplier was built on the supplier surviving due to the single customer that provided the work. Loyalty of the supplier to their only customer allowed for customers to have leverage over their suppliers, which allowed them to trust their suppliers more with little verification needed except for tracking on-time delivery of quality products.

The motivation of this research is to improve supply chain performance with the overall goal of improving supplier delivery performance through increasing customer supply chain risk management capabilities and by enhancing their supply chain transparency. Additional background and motivation is delineated in Section 2.1.

1.2 AIMS OF THE RESEARCH

The focus areas of the research are: creating a real-time metric package by establishing an initial set of metrics to increase transparency and aid in risk management, creating criteria to select the metrics to deploy with suppliers, additional work in the area of predictive metric packages are presented including creating a risk model to rank suppliers based on the real-time metric package and the corresponding customer actions to take based on a suppliers risk ranking.

The new predictive real-time metric package presented in this dissertation has been designed for supply chains of production programs and data was collected from suppliers in the aerospace industry. Potential metrics for inclusion were collected from various sources including public literature. A down selection process was used to create the initial metric package to be deployed with the suppliers. The new predictive metric package uses real-time predictive metrics, which are defined as metrics that provide insight to risks and allow for mitigation at a supplier prior to impacting the customer or the end user.

Trent (2010) states that suppliers need objective performance feedback in order to understand what is expected of them. The data provided in the new metric package is the supplier’s process data and is produced by the supplier and not their customer. The new predictive metric package is a management tool that can be used daily to improve supply chain performance through monitoring processes at different parts of the supply chain. In the past, this type of information was mainly collected after an issue surfaced and was usually collected only for short periods of time. The transparency of the new metric package affects the behavior of the suppliers and customer, allowing them to focus on processes and not just the parts moving through the processes.

1.3 CONCLUSIONS AND EXPECTED OUTCOMES

Outcomes of this dissertation include: an initial set of metrics, selection criteria for help in determining which metrics to deploy with suppliers, models to analyze to determine which of the collected metrics from suppliers correlated to supplier performance, including how strongly the metrics correlated to performance and models for real-time predictions and risk mitigation, a real-time metric package was created using criteria to enhance risk mitigation capabilities of a customer.

Future work includes continued research in the area of supply chain risk mitigation including examining other factors that impact supplier performance to customers. Recommended standard actions for supply chain professionals is another key area of future work along with standard work for reactions to metrics. Other areas of future work include sub-tier management using process data and relationship management data.

The remainder of this dissertation includes additional background/motivation and a literature review in Section 2, metric determination and collection in Section 3, supplier metric analysis in Section 4, prediction and risk modeling in Section 5, discussions and future work in Section 6, and conclusions in Section 7.

2. BACKGROUND/MOTIVATION AND LITERATURE REVIEW

When the dependency between companies increases, they become more exposed to the risks of other companies (Hallkas, 2004). Customers of a supply chain usually receive a contract from an end item user. The customer then breaks the program up into work packages, many of which are bid out to suppliers. Overall supplier work content can vary anywhere from 0% to 100% for a given production program for a customer with typical programs having between 50% to 80% supplier content. Most suppliers are independent companies that usually supply products to more than one customer in a given industry and many times to multiple customers in multiple industries along with supplying suppliers in the same supply chain. The relationship between a customer and a supplier can range from friendly to adversarial and can vary day to day.

2.1 BACKGROUND/MOTIVATION

Customers flow work down to suppliers for various reasons. Cost and technology are two main reasons (Hallkas, 2004). Customers today no longer can afford to be experts in everything. This limitation applies not only to being unable to produce parts at a low cost but also the inability to be a leader in the developing technologies needed to win contracts from end item users. Suppliers are often able to produce parts at a lower cost, because they focus on areas and aggregate the demand of several customers. Suppliers are also able to focus on a technology due to having a business focus that allows them to be on the cutting edge of technology for a given product. Many companies over the years have followed Dr. Deming’s advice, as stated by Evans and Lindsay (2011), urging businesses to establish long-term relationships with fewer suppliers, believing it would lead to increased loyalty and opportunities for mutual improvement, this relationship piece of supply chain management is critical and ever changing. The reduction in the number of suppliers being used by a customer may have helped establish more long term relationships, however, it also created more dependency on a given supplier by reducing available competition.

Relationships between customers and suppliers and suppliers with other suppliers have changed over time. A supplier to a customer can be a competitor to the customer in another area. As the dollars spent by a customer to a given supplier changes over time, the relationship between the two also changes. Today's suppliers have changes in percent of work from their customers and changes in profit margins on different products at different times from different customers. All of these changes impact the relationships between a supplier and their customers.

The customer currently manages a supplier and their supply chain using a variety of techniques. The most common technique is to allow a supplier to measure and manage their own activities since the customer is paying for the supplier to do this activity and to actively manage their suppliers on an exception basis as needed when a crisis occurs. The supplier's bid includes the cost they expend to manage themselves and their suppliers. Some suppliers flourish in this environment of hands off control, others incur numerous issues.

Currently, most activities and metric packages in supplier management are crisis management, either due to a quality or delivery issue occurring at an instant in time. Calling a supplier and asking for status of a part is a common management technique with today's metric packages. This type of metric package and management technique has the following attributes: the majority of communication between a customer and a supplier is conducted during a bad situation and, therefore, the relationship is based on periods of negative issues; an issue occurs at the customer, therefore, not enough time to correct the issue or mitigate the risk at the supplier costing the customer money and potentially impacting the end user's satisfaction; containment is only done with no true root cause and corrective action, large amounts of resources are expended at the supplier and at the customer; and damage to the ongoing relationship and the customer's relationship with the end user occurs. These attributes create an overall unhealthy atmosphere for the customer and supplier relationship.

The customer utilizes crisis management or recovery actions when a supplier causes an issue felt by the customer or incurs a risk that the supplier notifies the customer about. Many times the containment activities by the supplier and customer will prevent an issue from impacting the customer. The relationship part of supplier management is very valuable in these situations where trust is needed to work through difficult issues. However, when the containment actions fail or are implemented without enough time prior to deliver to the customer, the customer is impacted. With little true root cause corrective action taking place, the same issue can easily arise again. Many suppliers are managed this way without a detailed lower level strategy, using an ad hoc system of engagements and escalation, managing by exception only. If a given supplier does well in this environment, the customer and other customers are more willing to put more work into that supplier, pushing the supplier to their limits and possibly beyond their process capabilities and, thus, putting the hands-off management style in a position to fail. Suppliers are not in the business of turning down work from customers, which leads to this state.

The source selection process is relied on heavily today to manage the risk of procuring parts. Picking the right supplier at the start is considered crucial, even though many things can change seconds after the contract is signed. Tools such as supplier certification processes and source selection scoring systems based on past performance are put in place to help ensure on-time quality deliveries. These processes usually rely on a supplier providing a snapshot of the processes they will use to make the parts the customer wants. These tools push the customer to place contracts with high performing suppliers from the past. These tools have value; however, without insight into the changing processes at the customer and suppliers to combine with it, these tools can lead a customer to a false sense of security and force them to rely on fire fighting when issues arise. The most popular criterion for source selection are quality, delivery, price, manufacturing capability, service, management, technology, research and development, finance, reputation, relationship, risk, and safety and environment (Ho et al., 2010). Weighted linear programs for multi-criteria supplier selection process can used (Ng, 2008).

A frequently used strategy to manage suppliers in the supply chain is for the customer to place people on-site at the supplier. This technique has some drawbacks. The expense of placing a person at a supplier is high. Also, once a customer employee is located at a supplier for a length of time it is said the employee goes native and acts more like an employee of the supplier, putting the supplier interests ahead of the customer's interests in many cases.

Another frequently used strategy to manage suppliers is to place the suppliers on a min/max or consumption based ordering contract. This allows the supplier to supply parts within a range at the customer. Ki-Seok (2004) showed that this type of arrangement can allow a supplier to avoid stock out situations at their customers. This management process places emphasis on a supplier to be able to manage their processes based on the consumption of the customer and does not allow the customer to know there is an issue until a threshold of on-hand parts is broken.

Another supplier rating technique used by customers is to use maturity models to rate their suppliers. The customer requests a supplier to fill out a questionnaire and then may follow up with a visit to quickly verify the supplier's answers. These snapshots in time are used to determine the health of a supplier and help the customer determine where to send resources to help suppliers improve and where to locate customer employees on-site. Some current metric packages and management techniques at customers tie their supplier management employee ratings and their pay raises to the supplier performance those employees manage, which puts the employee in a position to adjust contracts as needed to allow their suppliers to look good so they look good and receive a larger raise.

Current metric packages focus on delivery and quality performance using past data and are not real-time or predictive and do not take into account the process used by suppliers to produce the parts. For example, gold, silver, bronze, yellow and red levels are frequently used to give an overall static picture of a supplier for delivery and quality based on past performance to the one customer who receives the delivery from the supplier. Most rollups or dashboards used by the customers are snapshots in time and are not data trends over time. Little, if any, effective future prediction analysis is used in this performance analysis except for assuming good performance in the past for a given customer will mean good performance in the future for the same customer. A rolling average is also frequently used to track suppliers for this delivery and quality data. Problems with using this methodology are shown in the next two examples. If a gold supplier recently lost 90% of its workforce it would still be rated as a gold supplier until it failed on deliveries or quality in a quantity to move the overall rating below gold. With this gold rating a supplier who just lost 90% of its workforce could receive a critical contract even though they are not in a position to execute the contract. The rolling average masks the future and current performance capabilities of a supplier. Another example of this masking is a supplier that had one bad batch of parts 11 months ago and was perfect for 5 years prior to the 11 months after the bad batch. The customer today using the rolling average methodology would not want to place work with the red supplier due to their poor performance and the projecting of that poor performance forward, even if root cause corrective action had taken place.

The subject of supply chain management has received considerable attention over the last few years due to customers of them moving up the value chain and increasing their reliance on suppliers and the supply chain along. Considering the importance of supply chain management to customers this increase in research is not surprising. A critical review of literature on the topics of risk, metrics, and prediction revealed some insight into how to perform the job of managing suppliers using real-time process metrics and models and how to develop such a metric package. Literature was found regarding different types of risk tools, metric packages used with suppliers, and prediction capabilities within the supply chain. However, no literature was found analyzing an application of a real-time metric package to a group of suppliers and determining if the metrics collected correlated to the supplier performance.

2.2 RISK MITIGATION

Dyer (2000) examined the collaborative advantages of using an extend supplier network in the automotive industry at Toyota and Chrysler. Stating that competition is no longer one company versus another company, it is now one company and its supply chain versus another company and its supply chain, Dyer proposes that close partnerships where needed within the supply chain are critical to a company’s success. Treating business partners as though they were inside of your company allows for better information sharing and trust which is based on fairness and predictability. The work in this dissertation expands on this by taking internal process metrics which are shared within companies and shares them across companies. Dyer states that vertical integration needs to move to virtual integration in many areas and that arm's length procurements are becoming obsolete in complex product industries due to not sharing knowledge and information to coordinate activities effectively to produce a differentiated complex product. Dyer cites the advances in computing, data collection, and telecommunications across firm boundaries as being critical to advancing partnerships and is needed for the supply chain to act like a single firm though firms naturally do not trust each other or share information. Dyer shows that Toyota uses multiple just in time deliveries per day to enhance their communication with their partners who are at times physically located close to their production facility. Toyota also works directly with suppliers to improve supplier performance by having Toyota workers co-located at their suppliers' facilities. Though Dyer does not share which exact metrics are shared at these process improvements events or what process data Toyota continually collected from suppliers, these improvement events and co-located Toyota employees do require process data sharing similar to the process data sharing shown in this dissertation. Toyota also audits suppliers to see if they are improving their processes. The Toyota supplier scorecard contains scores for management, production, costs, quality, and delivery. Dyer then states that the only sustainable competitive advantage for a company is to learn faster than other companies. The work in this dissertation expands on this by increasing the use of process metrics and models in supplier management. Dyer also concluded that suppliers performed differently for different customers. This dissertation expands on this work by an analysis of the preferred customer status of the customer collecting the supplier process metric versus the supplier performance to other customers.

Pfleeger (2000) states that risk is an unwanted event that has negative consequences and that there are three strategies for risk reduction: avoiding the risk, transferring the risk, and assuming the risk. More research on modeling of supply chain risk is needed to understand the sources of supply risk and how to manage them (Wu, 2006). Other tools used in the management of supply chains are discussed by Wu (2006) including theory of constraints and managing demand fluctuations. Several risk factors have been identified in a literature review by Wu (2006). There is however a gap in literature for analyzing risks from root cause and fitting them into a risk management methodology declares Wu (2006) and this research attempts to close this gap by focusing on root cause corrective action based on a methodology using the processes at a supplier and a stability and capability analysis. Many risk factors were reviewed in the making of this new metric package that focuses on supplier processes. The research in this dissertation expands on the modeling of supply chain risk by analyzing metrics for the processes at suppliers which will provide inputs for supply chain risk models. These tools can be used in the root cause corrective action that is required due to the risk rating of a supplier using the model for the future areas of work of this dissertation.

Thun and Heonig (2011) studied supply chain risk management in the automotive industry, stating that globalization, complexity, just-in-time, and just-in-sequence have created a more complex supply chain network. They performed analysis on internal and external supply chain risks and how automotive companies manage them, either in a reactive way or a preventive way. Their results showed that companies using a preventive supply chain management risk approach were more flexible with their supply chain, able to decrease stock outs, had better reactivity to issues, and were able to reduce costs. They believe managers do not implement suitable instruments for supply chain risk management due to their lack of understanding the likelihood and impact of the risks in their supply chains. However, Thun and Hoenig (2011) do not provide guidance on how to achieve this. The work in this dissertation builds on their work by providing a real-time metric package to collect data from suppliers that will allow for improved supply chain risk mitigation, that in turn will allow a company to realize the benefits that Thun and Hoenig (2011) uncovered in their work, a more resilient supply chain.

Tuncel and Alpan (2010) use a timed Petri nets framework to model and analyze a supply chain network subjected to various risks. Their research uses a failure mode, effects, and criticality analysis to integrate risk management procedures into the design, planning, and performance evaluation process of supply chains using a Petri net based on simulation. Tuncel and Alpan (2010) describe the four steps to risk management as: risk identification, risk assessment which includes the likelihood and consequences of the risk, risk management actions, and risk monitoring. Their research looks at potential failure or risks within a supply chain including: decline in business relations with supplier, raw parts scarcity, breakdown of machinery, fluctuations in customer demands, quality problems in manufacturing, late deliveries, low profit rates, lack of training. Their research includes detection or controls including: collaboration, risk sharing, statistical quality control, inspection, communication and information sharing, maintenance, statistical process control. The severity, occurrence, and detection or current controls are each given a score with an overall risk priority number being generated from the three scores. The number one risk using their approach was a supplier's subsystems that can create quality problems in manufacturing which can result in poor quality products to a customer. Their number two risk is maintenance issues leading to instable manufacturing processes. Their conclusions included a 9.9% increase in customer fill rate when mitigation actions are put in place to reduce risk factors to a moderate level and a 7.9% increase in customer fill rate is mitigation actions are put in place at a low rate. Quality risks were determined to provide the most efficient results. Their conclusion that risk management actions have a great impact on performance is built upon by this dissertation. Moving from a reactionary supply chain management strategy to a preventive risk management strategy is the basis of the real-time metric package presented in this dissertation that includes quality metrics. The use of statistical process controls on the data collected also builds on their work as an effective risk mitigation tool.

Kristensen, Aven, and Ford (2006) study what is risk and how should it be characterized. Using the German Government's Advisory Council on Global Change they created a predictive Bayesian risk classification scheme. This scheme includes the following nine characteristics: potential consequences, uncertainty about consequences, ubiquity, persistency, delay effect, reversibility, violation of equity, potential of mobilization, difficulty in establishing appropriate performance measures. Their work is built upon in this dissertation by including the delay or lag effect of risks on the outcomes. Including the lag effect in the data analysis allows for a more complete view of the risk being mitigated.

Tah and Carr (2001) study the construction supply chain and risk management for construction projects. Their work focuses on the need for a knowledge management system to capture and track risks for a project. Advocating for a common language regarding the classifying and quantifying the severity of risks, Tah and Carr (2001) develop a use case diagram showing the activities and resources used in risk management along with a hierarchical risk breakdown structure. Stressing that communication of project risks is poor and that people working within the same system are using different terminologies and methods for dealing with risks that are producing conflicting results, Tah and Carr (2001) state that early warning systems are not effectively implemented and contingency plans are not adequately created and lessons learned are not shared. The work in this dissertation attempts to fill these gaps by developing standard well understood metrics and using simple data analysis including control and specification limits to improve and simplify communication. Also, knowledge management is addressed in this dissertation by tracking supplier processes and performance over time along with collected root cause and corrective actions taken based on the data collecting in the real-time metric package.

Blome and Schoenherr (2011) analyzed supply chain risk management during a financial crisis. The work in this dissertation was done during a financial crisis also. Supply chain risk management has become a key concern for industry and 90% of firms surveyed felt threatened by supplier risks resulting in a customer needing to be able to better detect, predict, avoid or reduce the effects of supplier disruptions (Blome and Schoenherr, 2011). This dissertation does not include financial indictors as suggested by Blome and Schoenherr (2011) but is included in the future work area. Blome and Schoenherr (2011) did reveal that customers have shortened their review cycles for suppliers during the financial crisis, some customers moving from yearly or half-yearly cycles to weekly. The work in this dissertation expands on this review cycle time reduction, moving to weekly supplier data collection, even allowing for daily collection if needed.

Overall literature points to the conclusion that supplier management has been in need of dramatically improving their measurement systems for some time. Drzymalski (2008) declares that supply chains today have increased risk of noise and unreliability. Increased control is needed as supply chain performance and customer needs change over time (Gunasekaran, 2004). This dissertation attempts to increase the control capabilities of a customer by using a real-time metric package.

What is missing in literature in this area is a metric package that has been created, data collected from a supply base, data analysis to determine which metrics correlated to supplier performance, and then a daily risk mitigation template based on a risk rating of suppliers. This dissertation attempts to fill these gaps.

2.3 CREATING METRIC PACKAGES

The Supply-Chain Operations Reference (SCOR) model (www.supply-chain.org) focuses on wealth creation as a result of performance and on past performance. The SCOR model is a process based approach to address and improve processes along with communicating to all concerned. The model addresses sub-tiers and includes three sections, plan, source and make, believing the size of the supply chain does not matter. Three levels of process detail are measured including types – scope/content, categories – configuration/type of supply chain, and decompose – compete in markets. Over 125 key performance management indicators are listed along with best practices in the SCOR model. Once a performance gap is measured and identified over 400 practices are listed to guide the user. The SCOR model does focus on past information; however this can be used for predictions. Presutti (2007) shows that linking the SCOR model to economic value added is critical. Hugos (2006) shows how to apply the SCOR model to given situations including the use of distributors. These articles show the value of using the SCOR model and its acceptance in industry and was used in this dissertation as a starting place for the initial metric list. Common metrics listed in the SCOR model and tracked by customers include earned value management, first pass yields, on time to schedule via a line of balance, and actual versus quoted cost.

Otto and Kotzab (2003) studied supply chain management and examined six perspectives to measure the performance it. System dynamics, operations research, logistics, marketing, organization, and strategy perspectives were reviewed. Degree of capacity utilization was used as a key performance metric. This dissertation builds on this by using metrics to increase the transparency between the customer and their suppliers in the area of capacity. Future work in this area will combine the metrics in this dissertation with more traditional capacity metrics including machine utilization and others.

The Balanced Scorecard from Kaplan and Norton (1996) focuses on financial items but also discusses how operational, marketing, and developmental items impact performance. Measuring things that impact the financial standing of a company is critical. Process performance, market share, and employee skills are three key metrics listed by Kaplan and Norton (1996). A matrix is provided to review all levels of performance within the company regarding financial, customer, internal business, and innovation and learning. The Balanced Scorecard is required reading when developing any internal or external metric package. The real-time metric package created in this research builds on the it by adding a daily management tool into the tool box of the supply chain professional managing suppliers and using metrics that are standard to rating the performance of a supply chain management group.

Lehmann and O'Saughnessy (1982) determined that five categories were the key to supply chain metrics: economic, adaptive, performance, integrative, legalistic. Bhagwat and Sharma (2007) list key metrics for performance measurement for supply chain management. These metrics include placing orders on time and capacity utilization along with delivery performance. The research in this dissertation builds on both of these by focusing on the performance aspect of supply chain metrics. Collecting real time process metrics of suppliers highlights the performance capabilities of a given supplier.

Sauder and Morris (2008) believe that the simpler the supply chain metrics are the better and were not in favor of the SCOR model due to its complexity. Keys for their metrics are automation of the data collection, a core set of metrics, and open shared data that is a small set yet is actionable and standard and can apply to many suppliers. The research in this dissertation builds on this by using a simple set of process metrics that are currently in use by manufacturing facilities around the world. Automation of the data collection was also used due to the need of a long term cost efficient solution versus manual collection of data. A standard set of core metrics that is actionable was also developed and correlation analysis to supplier performance was done in this dissertation. Using capability and stability analysis along with root cause corrective action in the models allows for a standard risk management process that can be applied to many suppliers by a customer.

Huang and Keskar (2007) developed seven categories for metrics; reliability, responsiveness, flexibility, cost and financial, infrastructure and assets, safety and environmental. The categories are then put into three groups: supplier, product, and society. Focus on what type of product is being made, what type of supplier is doing the work and what is the integration level between the customer and suppliers was also studied. Huang and Keskar (2007) believe these items should be used to form a metric package. The individual application of the production program metric package to a supplier takes into account what type of product is being made for the customer and the type of work being done by the suppliers for the customer. The integration level between the customer and supplier is built upon using discussions between the customer collecting the data and the suppliers providing the data to determine the required level of integration needed to provide sufficient transparency.

Kleijnen and Smits (2003) recommended using a simulation model based on the Balanced Scorecard to understand how metrics react to managerial and environmental states and changes to show how the metrics are correlated. This dissertation builds on this by creating a risk level model and reaction model that are based on real-time supplier process data. The simulation of the performance of a supplier can be done by using the past collected data and the end delivery results of a supplier to simulate their future performance for a given situation and is included in the future work of this dissertation.

Table 2.1 shows an example of some of the metrics listed in literature and the metrics used in this dissertation.

Table 2.1 Metrics in Literature

			Literature		
	Gordon (2008)	SCOR Model	Tuncel and Alpan (2010)	Lee, Park, Shin (2009)	Teller, Kotzab, Grant (2011)
Metric					
On-time delivery of all supplier parts from supplier location	X				
On-time deliveries to supplier from sub-tier				X	
Quality of parts delivered to supplier from sub-tier	X		X		
Purchase contract on-time placement	X				
Internal quality of materials and parts		X			
Manufacturing releases		X			
Overtime for supplier			X		
Staffing – actual and plan		X			X
Maintenance hours – actual and plan		X			
On-time engineering release		X			
On-time delivery of quality corrective actions to supplier from sub-tier		X			
Quality of quality corrective actions to supplier from sub-tier		X			
Capacity utilization	X				X
Cycle times		X			
Inventories	X	X	X		X
Financial measures	X	X			
Safety incidents					
Warranty and returns	X	X			X
Available floor space					
Percent change in cost		X	X	X	
Shipment errors	X	X	X		
Fixed manufacturing costs	X	X		X	
Average cycle times	X	X			
Scrap and rework	X				
Products/mix profitability	X				
Demand variance	X				
Transportation schedules and costs	X	X			
Rework	X		X		
Reinspection	X				

Beamon, as stated by Huang and Keskar (2007), indicated metrics should satisfy all four categories: inclusiveness, universality, measurability, and consistency. Characteristics of an ideal metric package as stated by Trent (2010) include flexibility, are used by internal customers, are reviewed by suppliers' top management, segment out to each supplier production location, are cost-based, are real-time, can separate the critical few from the many suppliers, have flexibility in data analysis, provide early warning, allow the suppliers to view their own data, and are benchmarked versus the best-practice companies of the world. Gordon (2008) states the characteristics of a good supplier measurement are meaningful, valuable, balanced, linked, practical, comparable, credible, timely, simple, robust, and of a reasonable number. Rajat (2007) states that goals of an organization being tied to specific measures are critical for creating an internal scorecard or one that is being applied to a supply chain.

Davenport and Harris (2010) point out the key items needed to drive change to a more analytical world and was also used for the initial metric selection. High quality accessible data is the first step. The customer can not be a great analytical company without data. A customer will never have every piece of needed data at every instant in time, however, a more complete picture can be painted using real-time metrics. For data to bring value Davenport and Harris (2010) state it must be structured, unique to bring a competitive advantage, integrated, of sound quality, accessible by the users, guarded as needed, and governed to bring it all together. An enterprise orientation is listed second by Davenport and Harris (2010) as being critical. An enterprise orientation allows for the sharing of data and the leveraging of skills and abilities at the customer. It also allows for resources to be spent more wisely including improvement projects at select suppliers which lead to long-term benefits for the suppliers and customers (Talluri et al., 2010). Without an enterprise wide view, the views are disjointed and can promote sub-optimal decisions for localized gain. Third is analytical leadership according to Davenport and Harris (2010). This key element is necessary to set the tone for all the workers at the supplier and at the customer. Without this, the data is just data and not information. The fourth key item according to Davenport and Harris (2010) to drive change is strategic targets. Without targets there is little purpose in collecting data. Last item listed to drive change are analysts. Davenport and Harris (2010) state that without someone to use the data, the analyst, data will not be transformed into valuable information that action can be taken on.

What is missing in literature in this area is a simple small set of standard metrics that are rated using daily supplier management criteria and then applied to a supplier group to determine their effectiveness. Building on these items in literature was done by focusing on the different categories of metrics along with the different techniques to build a metric package and how to implement it. The SCOR model was used as a starting place for the creation of the metric package in this research. The SCOR model and the use of past information is built upon by adding the new real-time supplier process metric collection along with analyzing capability and stability of the process being measured.

2.4 REAL-TIME ANALYSIS AND PREDICTION

Lapide (2006) states that the excellent supply chain has the following four attributes: part of the company's strategy, leverage of the supply chain model creates a competitive advantage, does well versus competitive operational performance objectives, focuses on a limited number of business practices. The company then must balance the excellent supply chain with other factors including customer response, efficiency, and asset utilization into an overall company strategy that provides a competitive advantage. Tying the supply chain to the company's strategies is critical for several reasons including technology advancements and partnering situations. Leveraging the metric package can create a competitive advantage regarding cost, delivery, and quality. The research done to create the real-time predictive metric package and models builds on this concept by highlighting the need for a deployment strategy for the metric package to be aligned with the company's new strategy, in this customer's case, to move to a trust but verify relationship with their suppliers instead of a trust relationship only.

Lee, Park, and Shin (2009) studied large engineering project risk management using a Bayesian belief network and applied it to the Korean shipbuilding industry. Modeling of conditional probability relationships is valuable when working with complex problems under conditions of uncertainty. Determining the causal relationships allows for probabilistic relationships to be modeled and allows for the building of a cause and consequence diagram. Project success criteria measured was schedule, cost, and technical performance. Risk categories reviewed by Lee, Park, and Shin (2009) included natural, political, legal, social, economic, financial, technical, and managerial. Risk items for these categories included cost overruns, schedule overruns, strikes, quality issues, productivity issues, specifications issues, equipment failures, new technology issues, changes in design, cash flow issues, changes in tax, exchange, and interest rates, and supply of raw materials. Key risk items for large-scale shipbuilding companies were calculated to be raw material issues, exchange rate changes, design manpower issues, design changes, requirement issues, and capital funding. The work in this dissertation builds on their work by creating a model to allow users determine an overall risk rating for a supplier. This overall ranking will allow users to then determine how much resources to apply to different suppliers based on their amount of risk measured. The concept of adding new variables not included in the real-time metric package is reviewed in the future work of this dissertation and takes into account work from Lee, Park, and Shin (2009) and their wide range of metrics being analyzed and included in the model.

Tang (2006) provides a comprehensive review of supply chain risk management looking at literature in the areas of supplier selection process, order allocations, demand management, product management, information management, and robust strategies for mitigating operational and disruption risks. One of Tang's main goals is to motivate researchers to develop new models for mitigating supply chain risks due to the gap between theory and practice and the lack of explicit solutions in this area. This dissertation attempts to help fill that gap by creating a model, applying it to a supply base, and determining which metrics correlate to supplier performance and therefore should be collected from suppliers. Tang (2006) states that supply chains impact firm's short and long term performance and that firms suffering from supply chain disruptions experienced 33-40% lower stock returns when compared to their industry benchmarks. Tang simplifies supply chain risk management into four basic approaches: supply management, information management, demand management, product management. Tang places supply chain visibility in the category of strategic plans in information management and puts information sharing in the tactical plan category along with collaborative planning, forecasting and replenishment. Tang then reduces supplier management down to five inter-related issues: supply network design, supplier relationship, supplier selection process, supplier order allocation, supply contract. Tang states that supplier to customer relationships have shifted from adversarial to cooperative in the United States starting back in the 1980s. Tang's work is leveraged in this dissertation by asking the now cooperative suppliers to provide key real-time metrics to their customer, which in the past would have been seen as an intrusive request. This dissertation also attempts to fill a gap in most supplier capacity models that the supply capacity is unlimited or perfectly known as stated by Tang (2006). The real-time metric package in this dissertation actively tracks insight into supplier capacity by collecting data on a regular basis from suppliers in this area.

Tang (2006) also shows that managers are insensitive to the estimates of the probabilities of possible outcomes of risk and instead mainly focus on critical performance targets which affect the way they manage risks. Most managers as explained by Tang do not trust or understand or do not use precise probability estimates. They do not look at expected loss; they look at the worst case usually and are rewarded for obtaining good outcomes, not necessarily making good decisions. Tang (2006) goes on to state that most companies recognize the importance of risk assessment programs but invest little resources for mitigating supply chain risks since managers do not get credit for fixing problems that do not occur. Tang (2006) states that companies would be more willing to implement a strategy for supply chain risk management if the strategy if efficient and resilient. The real-time metric package and work in this dissertation attempts to fill this efficiency gap by being easily understood by users, using information technology in risk management (Teymouri and Ashoori, 2011) and resilient by being standard and used over time.

Schmitz and Platts (2004) studied supply chains in the automotive industry and found there is much work done on the practice of performance measurement within an organization but much less regarding the practice of supplier performance measurement. Stating that performance measurement is not the safe secret to success, but that managers would feel uncomfortable without it, Schmitz and Platts (2004) collected the functions of performance measurement from several literature sources. The functions of performance measurement as stated by Schmitz and Platts (2004) are: strategy formulation and clarification, management information, vertical communication, horizontal communication, decision making and prioritizing, coordination and alignment, motivation, learning. This dissertation builds on this by creating a real-time metric package that allows for management information, vertical communication, horizontal communication, decision making and prioritizing, and learning. The real-time metric package in this dissertation provides supplier process information to make real-time decisions with, is shared within the entire enterprise collecting the data and therefore promotes horizontal and vertical communication, allows for decision making and prioritizing by providing prediction capabilities for future issues, and begins the process for learning by bringing statistical process control methodologies into supply chain management. The number one aspect that Schmitz and Platts (2004) found for supplier performance measurement is communication. The work in this dissertation addresses that by creating an atmosphere where the supplier and the customer are looking at the same data provided by the supplier, not just the performance data collected by the customer on the supplier, thus enhancing communication.

Xia and Chen (2011) researched relationships in a supply chain to help create a decion-making model for risk management. They reviewed three types of relationships: bilateral, unilateral, and inter-circulative. Types of risks were also reviewed by Xia and Chen (2011) and include: competence, machine stability, planning capability, transportation methods. Their conclusion that the dynamic nature of the supply chain requires an inspection of the relationships within the supply chain is built upon in this dissertation. Making predictions based of the relationship between the two companies along with other inputs can increase the accuracy of the predictions and allow for tracking of the outcomes and is discussed in the future work of this dissertation.

2.5 CONTRIBUTION TO LITERATURE

Supply chain management has been studied by a number of academic fields including marketing, operations management, management science, purchasing, and logistics (Ketchen and Giunipero, 2004). The overall literature review showed that much thought has gone into collecting metrics. As Tang (2006) states, there are thousands of articles published in the area of supply chain management and all were not reviewed for this dissertation. However, even with thousands of articles being produced, most items discussed are reactive in nature and do not allow for simple easy to understand predictions for use in the daily management of a supplier or supply chain. The majority of metrics look at a supplier's or supply chain's past or at best current health. Overall the literature in this area can assist a supply chain professional, however, the fluidity of the supply chain environment makes it difficult for one to know what to apply to one's given situation and when to apply it in a practical way and then when to change to something different.

What is missing in literature in this area is real-time data analysis and prediction using supplier process data. The project also adds value to the existing literature because many supply chain professionals are not happy with the current metric packages being used today (Trent, 2010). Issues with the current metric packages include not being real-time, do not provide predictive capabilities, and do not provide risk mitigation abilities. Sukati (2012) showed that strategic partnership and information sharing is a strong predictor of supply chain performance.

3. METRIC DETERMINATION AND COLLECTION

The initial metric collection utilized foundational elements from literature to create the initial list of metrics. The difference between information and insight is shown by Davenport and Harris (2010) in Table 3.1, and shows a gap that the research in this dissertation is trying to close. Using metrics that move the users from asking what's happened to asking how did it happen and what will happen next is critical to gaining insight.

3.1 METRICS STUDIED

The relationship between these four metric categories are that the financial impacts how well a supplier can manage its supply chain, what type of resources it uses in manufacturing, how well it treats its people, and how it treats it customers. Supply chain management impacts the other categories; do their suppliers allow for proper manufacturing techniques to be used. People impacts all the other metric categories. The skills and attitudes of the people impact how they manage their supply chain, how they make things, their overall financial health, and how they treat their customers.

Table 3.1. Data Versus Information (Harris, 2010)

	Past	Present	Future
Information	What happened? Reporting	What is happening now? Alerts	What will happen? Extrapolation
Insight	How and why did it happen? Modeling, experimental design	What's the next best action? Recommendation	What's the best/worst that can happen? Predict, optimization, simulation

These categories are important to the customer of the supply chain and are standard metrics of performance collected by customers of their suppliers. Cost, quality, schedule, and technical are also tied together. The feedback loop is critical to understand the influences various activities have on each other.

The SCOR Model, which focuses on the five performance attributes of reliability, responsiveness, agility, costs and assets provided the following metrics: shipment errors, percent change in cost, available floor space, warranty and returns, safety incidents, financial measures, inventories, cycle times, capacity utilization.

Metrics were included due to their ability to be collected along with their perceived value to the customer. Metrics for literature and other sources were not included for various reasons including a focus on the production phase of a product, the inability to collect the metric, the perceived value of the metric for daily management by the customer, and past experience by the customer regarding past root causes for supplier issues and areas where continuous improvement projects had been focused for corrective actions needed for suppliers.

A generic model was developed to score the metrics versus a set of criteria. The generic model:

Where

J = number of criteria

M = # metric

$S^m =$ total score for metric m, n= 1, 2, 3, ……M (1)

$= \sum_{j=1}^{J} Q_j \, S_j^m$

Where

Q_j = weight for criteria j

S_j^m = score for criteria j for supplier m $\forall_m$

$\sum_{j=1}^{j} Q_j = 100$ (2)

Criteria for ranking all of the initial metrics was determined by using literature including the SCOR model, Trent (2010) and Gordon (2008). The following are the criteria each metric was measured against: estimated impact to on-time delivery, real-time mitigation ability, daily management value, standard, simple, deployable in the initial stage, and having a production phase focus. The criteria were selected in an attempt to down select to a set of metrics suppliers would provide to their customer during the initial data collection period without overwhelming the targeted suppliers with too large of a metric list.

Below is a description of why each criterion was selected.

Estimated impact to on-time delivery was used as criteria due to its value. This subjective ranking was due to the main goal of the real-time metric package, improving supplier delivery performance.

Real-time mitigation ability was used as a criterion due to needing metrics that provided meaningful data that was timely and actionable prior to impacting the customer.

Daily management value was used as criterion due to needing useable data. The new real-time metric package focuses on the daily management of suppliers.

Standard was used as criterion due to the need for the data from the suppliers to be comparable. No one metric package can be for all suppliers and all programs, however, driving to a more standard set can help not only the customer but also the suppliers who are providing the data.

Simple was used as criterion to help facilitate usage by users and to increase the supplier ability to provide the data.

Deployable in the initial stage was used as criterion due to needing practical metrics to enhance the probability of data sharing from the supplier to the customer and due to the focus on production programs, leaving developmental programs and spares programs for future research.

3.2 DATA COLLECTION

The suppliers selected for the test group were randomly selected by the leadership group at the customer collecting the data. The data for the real-time metric correlation analysis was collected from a variety of suppliers providing production parts to the customer collecting the data. The suppliers were not paid for the data they provided and the suppliers were told it was a voluntary and their decision whether or not to provide data.

Customer deliver data was collected within the customer by comparing contractual due dates to on dock dates for all of the deliveries from suppliers that provided data.

Both the customer and suppliers approached the data transfer as a first step in the direction of increased transparency with the future possibility of increasing the amount of data being provided by the suppliers. In order to increase buy-in from the suppliers, the customer allowed them to pick the quantity and which metrics of the twelve requested metrics they would transfer.

3.3 ANALYSIS METHODS

The deployment included the design concept of when to react to variation and when not to, though the initial data collection phase included no reactions to the data. Reactions are not free; the cost of resources and impact on supplier relationships can be large. Common cause variation and special cause variation define the two types of variation. Special cause has an assignable cause and can be isolated with root cause corrective action usually, where common cause variation can be reduced by reviewing the process and selecting areas of the process to reduce variation from. The new metric package tracks processes over time and uses control limits to determine process stability. Control limits are calculated in this dissertation using standard well-understood control limit equations, plus and minus 3 standard deviations. Specification limits on processes were used to determine process capability and set with supplier inputs.

Examples of the four possible states of a process are shown starting in Figure 3.1. The stable and capable state is shown in Figure 3.1, the stable but not capable state shown in Figure 3.2, and the capable but not stable state shown in Figure 3.3. Figure 3.4 shows a process that is not stable or capable.

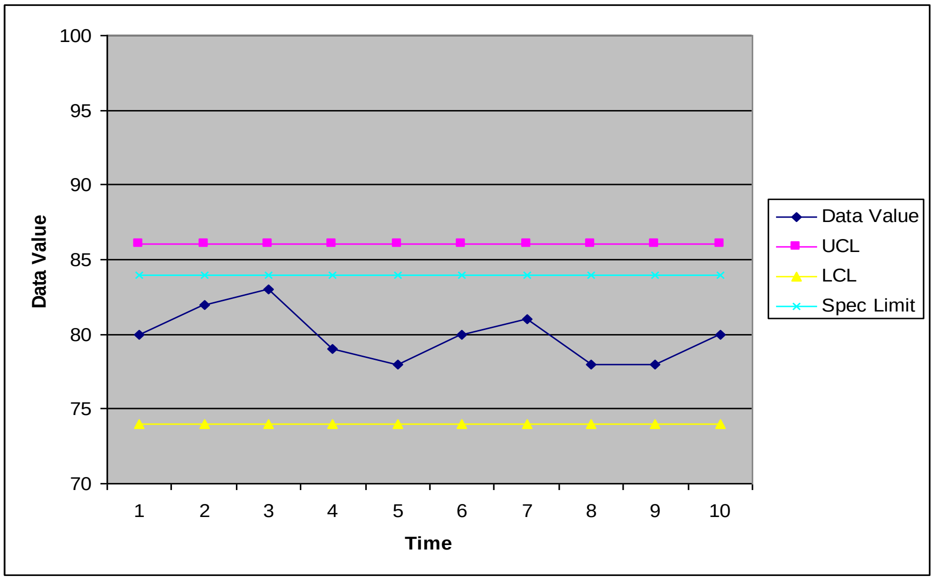

Figure 3.1. Stable and Capable

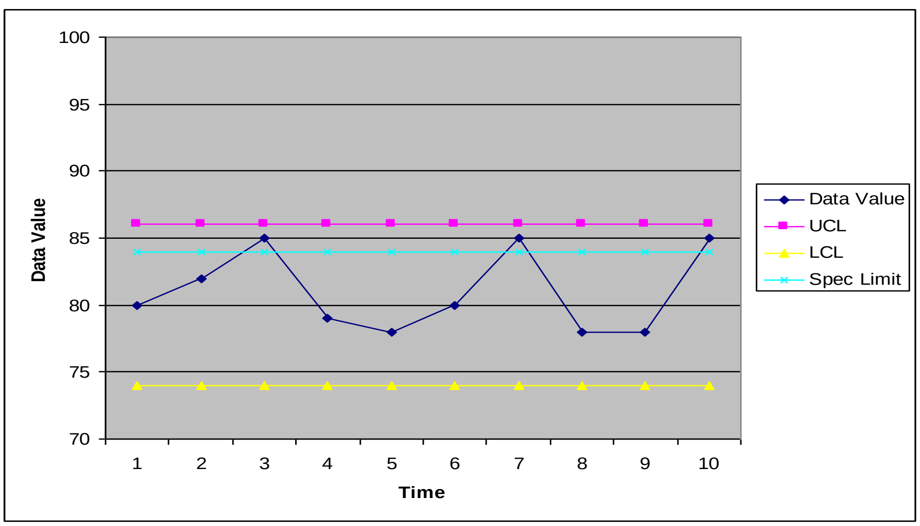

Figure 3.2. Stable, Not Capable

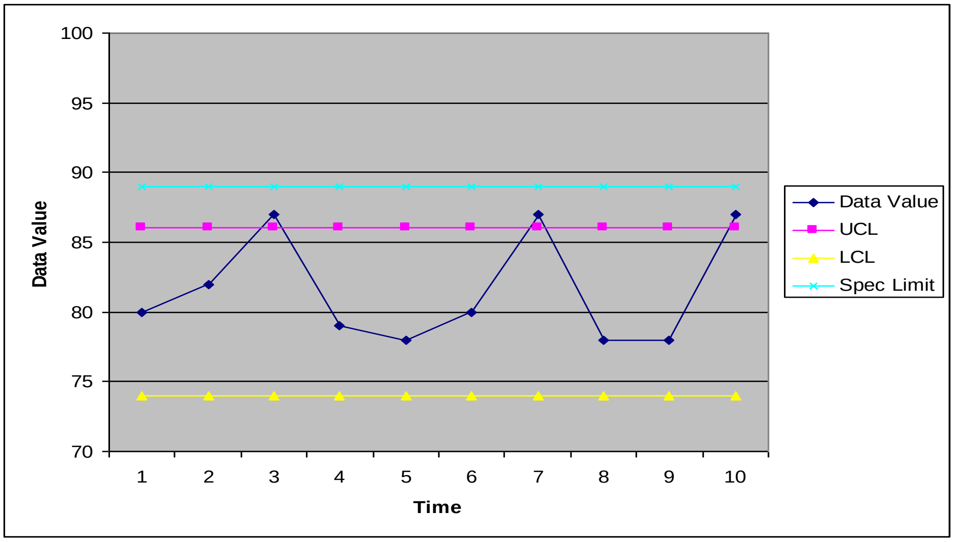

Figure 3.3. Capable, Not Stable

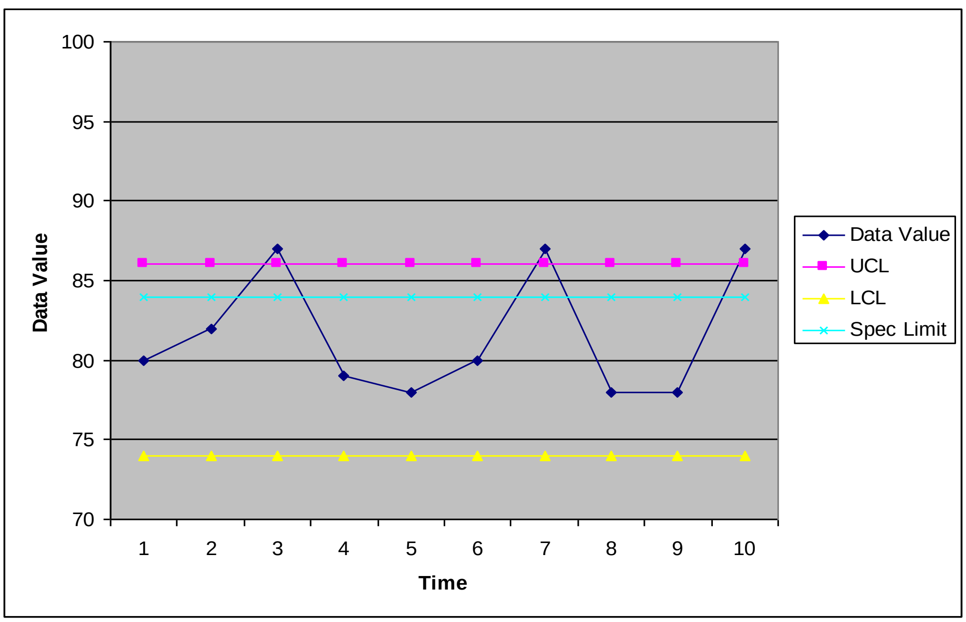

Figure 3.4. Not Capable, Not Stable

As Dunn (2006) states, the key to any metric package or scorecard is the utilization of the information.

The supply chain on productions programs can be very large, deep, and complex as shown in Figure 3.5.

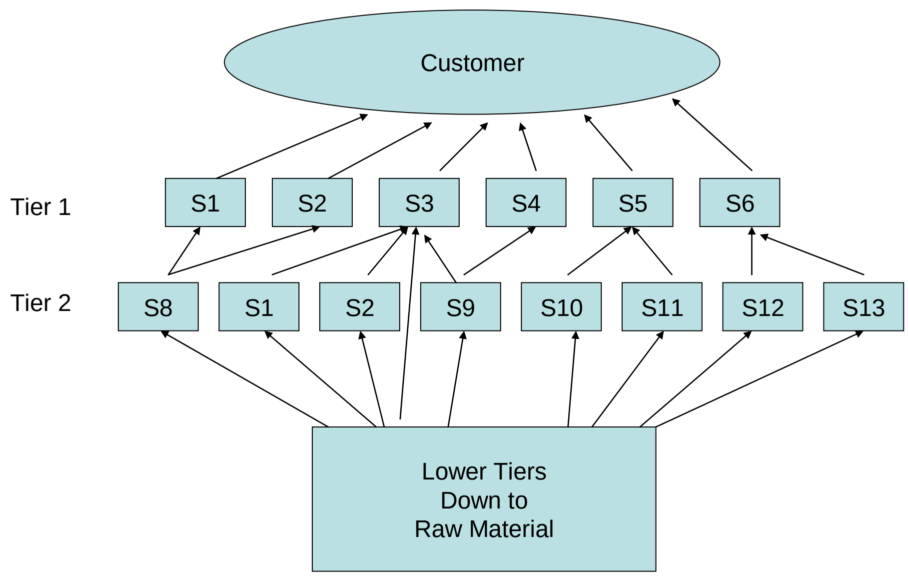

Figure 3.5. Supply Chain

The main supplier targets for the new real-time process measurement system are the tier 1 suppliers depicted as S1 – S6 in the simple supply chain diagram. However, the measurement system could be used directly with any supplier deemed critical regardless of the tier if all parties involved agree to share the data. For example, S10 could provide data directly to the customer if both S10 and S5 agree. (S5 agreement may not be required if a contract is placed directly between the customer and S10) Though tier 1 suppliers are the main targets, much can still be learned about tier 2 suppliers through the application of this model. Management of the sub-tier is a critical element in management of the first-tier.

4. SUPPLIER METRIC MODEL ANALYSIS

Section 4.1 focuses on the correlations between the collected supplier process metrics and the supplier's delivery performance to the customer collecting the data using linear regression models. The objective is to find the supplier metrics that have statistically significant linear relationships (or predictive power) with a supplier's delivery performance. The focus was not to build a forecasting model; it is to provide a supply chain professional with supplier metrics that can be used in the daily management of suppliers. The performance is formulated to be a linear function of metrics which have been transformed. Estimates of the regression coefficients can be obtained using the least squares solution technique. To make inference on true regression parameters, t-test was used by estimating regression parameters and its' standard errors. The *p-value* from the t-test is used to determine if the regression coefficient is significant or not. If the *p-value* from a t-test is less than 0.05 (a typical significance level), one can infer the metric corresponding to the regression coefficient has significant linear relationship with supplier's delivery performance. Thus, this analysis will provide insight into what metrics are useful in creating the supplier delivery prediction and actions models.

4.1 REGRESSION ANALYSIS

Multiple subsets of the original dataset were used due to the data availability as a result of not all suppliers providing data on same all metrics impacting data counts, suppliers beginning their metrics feeds at different times impacting data counts, and the results of a multi-collinearity test using Fisher 's Z test (uses normal distribution). Fisher's Z test was used to investigate correlations among all pairs of predictive indicators (X-variables). Next was to screen out one of the two X's if they showed significant correlation among themselves to avoid multi-collinearity situation in regression modeling. Thus, significantly correlated X's were not used in the same model simultaneously.

The overall regression model used in each of the three models can be, in general, described using the flowing linear formulation

$$Y=a+b_1X_1+b_2X_2...+b_iX_i+\ldots+ b_kX_k +e \tag{1}$$

where Y=days late for delivery to customer (dependant variable) from the supplier and X_i=*i*th metric collected from the supplier (independent variables or predictors), i=1,2,…,k and b_i is the regression coefficient of X_i, *a* is the intercept, and *e* is a random error term.

For each of the three regression models used, it is assumed that *e* follows a normal distribution with mean 0 and a constant variance. Whether a metric, X_i is positively or negative correlated with Y (delivery performance) depends on the sign of the regression coefficient b_i. For example, if the b_i is positive, the metric X_i is positively correlated with Y meaning that if the value of the metric goes up, the value of Y goes up. For a negatively correlated case, the value of Y goes down when the metric value goes up. The amount of change in Y depends on the magnitude of the regression coefficient. A t-test (uses student's t distribution) can be used to test for non-zero regression coefficient which will be described step by step. A test resulting in a *p-value* of less than 0.05 indicates that the metric is non-negligible and therefore statistically significant.

The effects of some of the supplier provided metrics may not be immediate; rather they may affect the delivery performance to the customer some time in future. For example, a change in the metric tracking the purchase contracts from a supplier to their suppliers may not influence the current delivery performance to their customer collecting the data; for example, it may take two weeks before any effect of the change is seen. To evaluate such lag effects, the past values of the metrics were reviewed and examined to determine whether current performance is affected or not. This chronologically backward looking approach was used to investigate if current delivery performance was correlated with past conditions of metrics. The lags are labeled as LAG1, LAG2, … which indicate the value of a metric 1, 2, …weeks in the past (when the metric is collected on a weekly basis) or 1,2,… months in the past (when the metric is collected on a monthly basis). The label LAG in parenthesis along with metric names for statistically significant metrics is provided when the lag values were used along with the current value of the metric. Lag 0 indicates the current value/state of the metric. The production cycle times of specific parts were not taken into account during the research for this dissertation. Though reviewing the lag time to determine a metric's impact on delivery is important on a part by part basis, understanding the supplier's processes and their impact to overall performance was the focus of the research in this dissertation.

The first step of the regression analysis in each of the three data sets begins with estimating b_i (the regression coefficient estimate) for all Xs (X_i=1,2,3,…k) using the least squares solution for all data collected using SAS software.

The regression equation for data set 1 is

$$\text{Estimated Y for data set 1} = a+b_1X_1+b_2X_2+b_3X_3+ b_4X_4 + b_5X_5 + b_6X_6 + b_7X_7 + b_8X_8 + b_9X_9+b_{10}X_{10}+b_{11}X_{11}+ b_{12}X_{12} + b_{13}X_{13} + b_{14}X_{14} + b_{15}X_{15} + b_{16}X_{16} + e \qquad (2)$$

The regression equation for data set 2 is

$$\text{Estimated Y for data set 2} = a+ b_{17}X_{17} + e \qquad (3)$$

The regression equation for data set 3 is

$$\text{Estimated Y for data set 3} = a+ b_{18}X_{18} + b_{19}X_{19}\ b_{20}X_{20} + b_{21}X_{21}\ b_{22}X_{22} + b_{23}X_{23}\ b_{24}X_{24} + b_{25}X_{25} + b_{26}X_{26} + b_{27}X_{27} + b_{28}X_{28} + b_{29}X_{29} + b_{30}X_{30}\ b_{31}X_{31} + e \qquad (4)$$

Model 1 used lags of 0 and lag 1. Model 2 used a lag of 0. Model used a lag of 0, lag 1, lag 2, lag 3, lag 4, lag 5, and lag 6. The different lags for each model were required due to the patchy data received from the suppliers during the data collection period and the regression requirement that all values must be present to use a row of data which consists of the metric for each lag and the Y value. The value b_i for i = 1,2,3,….k are estimated by minimizing the sum of the squared deviations, resulting in different estimates of the intercept for the three different regression models used. Using estimated b_is, intercept and values of metrics, one can obtain predicted value of Y.

The second step of the regression analysis is to calculate the standard error for estimate of b_i. This is the uncertainty in estimating b_i using a sample data set. Values of standard errors are obtained from multiple regression analysis using SAS business software. The standard error of parameter estimate is a function of the error of variance and goodness of model fit.

The third step of the regression analysis is a t-test to determine significance of the regression coefficients. The t-test is used to check if the true regression coefficient is equal to 0 or not by testing the null hypothesis that the true $b_{i\,=}\,0$ against an alternate hypothesis: true $b_i \neq 0$. If the test results in acceptance of the null hypothesis, it infers that the corresponding metric is not significant. On the other hand, if the null hypothesis is rejected in favor of the alternative hypothesis, it indicates that the corresponding metric has significant influence on predicting Y. If the *p-value* from the test is less than 0.05, we reject the null hypothesis and accept the alternate hypothesis which means the true $b_i \neq 0$ and therefore the corresponding metric (X variable) is significant. Next, repeat this test for regression coefficients corresponding to all the metrics used in the regression models.

The fourth step of the regression analysis is to determine the *p-value* for each X_i. The *p-value* is indicative of how extreme the value of observed t is compared to the distribution of t under the null hypothesis. If the observed t is around the center of the t distribution (under null hypothesis), then the coefficient is not significantly different than zero. If the observed t value is in the tail area of the t distribution, then the coefficient is significantly different than zero and therefore is having non-negligible influence on the value of Y as value of the corresponding X variable changes. When the *p-value* is smaller than 0.05, the null hypothesis is rejected and inference are made in favor of the alternate hypothesis.

Each of the three regression data sets used has different degrees of freedom due to the amount of data used in the model. The degress of freedom is based on the amount of data collected for a given supplier metric and usage of that metric in a particular model. The degrees of freedom is calculated for each metric using the following process: the number of data rows (customer delivery and supplier metric data in each row) minus 1 is equal to the total degrees of freedom. Knowing the mean, the last row is not independent and therefore the total degrees of freedom is the total number of rows minus 1. The model degrees of freedom is equal to the number of parameters being estimated, for model 1 this is 8 plus the intercept which equals a total of 9. The residual degrees of freedom or error is then equal to the number of data rows minus the model degrees of freedom. The degrees of freedom varied due to the data availability of three regression models. The residual (error degrees of freedom) degrees of freedom is the degrees of freedom for testing significance for the risk metric.

Logit transformation was used to the percentage data in an attempt to make effect of the metric more linear. Logit uses the natural log of (%/(100-%)). For the metrics overtime for supplier, supplier actual versus plan staffing, and supplier maintenance, log was used to make them linear due to these metrics having the ability to be greater than 1. Y versus X plots in the transformed scale showed a linear relationship therefore a linear model was deemed appropriate.

4.2 IMPACT OF QUANTITY OF RISKS

Monitoring a supplier's process performance to see if the processes are in control, within the process control limits, can help one understand the likelihood of future delivery performance issues. Does a supplier have more delivery issues as their number of out of control limit events for their process metrics collected increases?

5. PREDICTION AND RISK MODEL

Work in the area of reactions to metrics is needed to bring value to the activity of collecting data and turning the data into useful information. An example of this is provided by using the correlation analysis in this dissertation. The following supplier delivery prediction model was built to produce a supplier risk level rating and corresponding actions for a customer to take. The majority of models in use today are subjective, using ratings based on people's feelings about what a supplier has done, is doing, or is capable of doing. The supplier delivery prediction model presented in this dissertation as a start to future work in this area is based off the collecting of process data from suppliers and delivery data of the customer.

5.1 REACTIONS TO METRICS

A generic model of the supplier delivery prediction model is:

M = # of metrics

M = metric can range from 1 to M

P_m = points for metric m

$\sum_{m=1}^{M} P_m = 100$ (1)

S_m = stability points for metric m

C_m = capability points for metric m

$P_m = S_m + C_m$ (2)

R_j = rating for supplier j = $\sum_{m=1}^{M}(S_m^j + P_m^j)$ (3)

Where

S_m^j = stability score for supplier j and metric m

C_m^j = capability score for supplier j and metric m

$S_m, C_m \geq 0 \quad \forall m$ (4)

The movement or changes in the metrics provides a prediction of future delivery performance to the customer collecting the data. An iterative approach of reviewing actual delivery performance and the supplier process metrics collected along with reviewing if new metrics are needed for collection will allow the customer user and supplier to effectively apply the model in a changing environment. Each specific weight for the stability and the capability of each metric can be determined through use of the model and the knowledge of the root cause and corrective actions done by the supplier and the end result of on-time deliveries to the supplier. A point is allocated based on the weight to the supplier when their data is no longer stable (not between the control limits) or is no longer capable (not meeting the specification). Weights can range from evenly distributed for a simple model to those changing daily based on the specific circumstances a supplier and customer are facing.

Each supplier provided metric is plotted on a process behavior chart. The process behavior chart has calculated control limits and user determined specification limits. The control limits are calculated using +/- 3 standard deviations from the mean for the data of each risk metric collected at the customer level from the suppliers after 20 data points and excludes outliers. The control limits will capture 99.7% of the common cause variation in the process assuming a normal distribution of continuous data and define the stability of the process being monitored. Processes that are stable or in control receive 0 points while those processes that are not stable or in control receive a point allocation.

Specification limits are set collaboratively by the customer and supplier based on an iterative approach between the two parties and understanding of the capability requirements of each process being measured. The specification limit does not provide insight into the variation of the process. If the process is in a capable condition, then 0 points are awarded to the supplier. The total points, control limit criteria (stability) and specification limit criteria (capability) are added together to create a composite performance prediction score for a given supplier.

The outputs from the point allocations are used to determine risk rankings for the suppliers shown in Table 5.1.

The model has the following variables:

L= low risk parameter

H = high risk parameter

Table 5.1. Supplier Delivery Prediction Risk Levels

Supplier Rating	**Risk Score**
High risk	Rj>=H
Medium risk	L<= Rj<H
Low risk	0<= Rj<L

With limited resources at the customer to manage suppliers, adjustments to the model values L, and H in Table 5.1 can be made to the point scale of the model. This simple adjustment to the model can add tremendous value to the user and will also increase their buy-in if using the model for the first time. Table 5.2 shows the model with sample allocations for L and H of 10 and 30, respectively.

Table 5.2. Supplier Delivery Prediction Example

Supplier Rating	**Risk Score**
High risk	30 and above
Medium risk	Between 10 and 30
Low risk	0 up to 10

The simple classification of a supplier will allow users and their leadership to quickly understand the risk level of a supplier and be able to allocate resources accordingly. The values in Table 5.2 were determined with the goal of suppliers having key processes that are in control and capable in mind. Any process going out of control at a supplier requires a root cause and corrective action due to the special cause variation that created the out of control situation. Processes deemed not capable of meeting their needs of the overall process to make parts on time also need to be reviewed for continuous improvement activities to make them capable using the values in Table 5.2. In the previous supplier example a score of 40 was assigned to the supplier which would make the supplier a high risk supplier.

The model predicts which suppliers are more likely to encounter delivery issues to their customer based on being at a higher risk level. The model will allow a customer to apply resources where they are needed most and with the insight into which supplier processes are in need of improvement and can be used as a monitoring system once changes are made. The model can also be used as an input into a source selection model as a factor to compare a supplier to other suppliers regarding risk and the resources required to manage a supplier (Saen, 2010). Though a small amount of points move a supplier from low risk to either medium or high risk, the customer and supplier need to be aware of any process being out of control or not being capable of meeting the requirements placed on it.

5.2 ACTIONS

Without recommended actions the supplier delivery prediction model would be of limited value. The recommended actions taken by a customer based on the suppliers' performance risk score are described for each supplier risk category in Table 5.3. These actions were selected using inputs from various literature sources (Gordon, 2008), (Zsidisin, 2010), (Spector & West, 2006). Many risk systems today generate a risk level or risk number for a given supplier but provide little guidance or recommended actions thus creating an atmosphere where the scores for a model will result in no actions being to be taken.

The actions shown in Table 5.3 are fundamental problem solving steps and can be used in conjunction with other problem solving steps used by both the customer and supplier. Adjustments to the actions can be made as more experienced is gained using the supplier risk model, making the model a living model and increasing the value to the users. The actions in response to the model outputs are simplistic in nature. However, root cause corrective action has not been a consistently applied tool by supplier management professionals (Gordon, 2008). The escalation of risk within the supplier management function is becoming more frequent and is now expected within the function due to the increased pressures and visibility on supplier management groups.

Table 5.3. Actions To Supplier Risk Levels

Supplier Rating	Customer actions to take
High risk	Leadership escalation, request root cause corrective action for out of control process or process adjustments to improve process along with detailed impacted part analysis, supplier site visit to monitor or perform process improvement projects, increased communication with supplier including daily or weekly process and part status reviews, alternate suppliers reviewed if no change to risk supplier rating over time, require demonstrated improvement prior to placing more work with supplier, initiate supplier overall process review, conduct supplier capacity analysis on affected processes
Medium risk	Escalation, request root cause corrective action for out of control process or process adjustments to improve process along with detailed impacted part analysis, supplier site visit possible for verification, require improvement plans prior to placing more work with supplier
Low risk	Minimal, request root cause corrective action for out of control process or process adjustments to improve process, however, if delivery issues arise increase actions taken with supplier

Though the supplier delivery prediction model is simple, simple models often are the most effective models and are embraced by the users. This daily management model shown in will move the supply chain professional to a state of comfort using not only the models but process data and its analysis in general. The simplicity of the point allocation system will also remove confusion regarding the output of the model. This is important due to many users looking at the results of a model and not understanding how the end results of the model were derived, and therefore not buying into the results of the model or the actions needed as a result of the model. The user of the model will be moved painlessly from a non-analytic position on insight to a new position of insight using powerful data and analytical tools. Data generated stability and capability analysis will enhance their overall ability to manage suppliers in a changing environment.

6. DISCUSSION AND FUTURE WORK

The need for a new metric package that is real-time and proactive is based on competitive environments, increased use of suppliers, suppliers working for multiple customers, and customer and end item user expectations of a more transparent supply chain. A characteristic of an effective supply chain measurement system is that it is real time (Trent, 2007). Supply chain managers are not satisfied with the systems or approaches they are using to manage their suppliers (Gordon, 2008). This need to be proactive is not met by current metric packages that are usually backwards looking and are not usually real-time or supplier process oriented. The competitiveness to produce products has increased due to lower barriers to entry and global competition in many areas. The competitive environment has forced both customers and suppliers to outsource work to companies who can do it better, faster, and cheaper. This increased rate of supplier usage requires proper supplier management, to the same level if not higher than the level of management that was placed on the activities when the tasks were completed within the company who is now outsourcing the work. Suppliers are acting as competitors to customers and suppliers to other suppliers and this has created a complex weave of a supply chain across different products. In the past trust was a main component of a supply chain strategy. That trust now requires verification due to the complexity of the supply chain and the ever changing relationships inside of it. End item user expectations on customers and suppliers for a transparent supply chain will also create the need and drive culture changes if the customers and suppliers do not move fast enough.

6.1 DISCUSSION

The future of real-time metric package includes the targeting of processes for continuous improvement projects at suppliers and at customers. The new metric package shows a connection between the processes at suppliers and customers and their impact on delivery and quality. Customers today spend many resources with suppliers conducting continuous improvement projects. With the new metric, future projects will be more targeted and increase the return to the customers and suppliers.

Current and future capacity within a supply chain is critical. Tracking the key processes using real-time metrics as a supplier ramps up or down would allow a customer to understand how a supplier adds to their capacity or uses existing unused capacity. The insight from the metric package can be used with other capacity collection items including number of machines and available hours to understand a supplier's capacity. Knowing when a contract is signed, does a supplier have a good plan in place to meet the capacity requirement? Are they executing the plan to ramp up? These critical questions can be answered from the information taken from the collected data and other currently used management techniques including on-site reviews with a supplier reviewing machine utilization. Capacity tracking that relies only on a supplier survey to indicate their capacity without any verification is risky. Does the supplier have the tools in place and just needs to add a shift? Does the supplier need to buy a machine that takes 6 months to get to add capacity? Tracking the history of a supplier's capacity and their performance to the customer can determine if the initial capacity analysis was correct and what adjustments are needed.

The supplier management professional that does the contract negotiations with suppliers will be able to use the model in the future to incorporate a risk factor into their supplier selection process. Adding this risk factor to the supplier bid price, past performance, and management evaluation will allow for the customer to make a better best value supplier selection. Capacity analysis from the collected process data can also be used in source selection. The detailed process data and management model will allow the supplier management professional a level of transparency into contract negotiations that not only could save the customer money but could also reduce contract placement risk on-time delivery risk.

6.2 BEHAVIOR CHANGES

The behavior changes due to application of the supplier delivery prediction model in this dissertation using the new real-time proactive metric package are numerous and substantial. The early findings from deploying the real-time process metrics and models showed that changes in behavior are coming in several areas. A change in behavior at the customer, a change in behavior at suppliers, a change in the relationship between a customer and a supplier, a change in the relationships between members of the supply chain, and a change in relationship between the end item user and customers are now expected. Increased confidence for the end item user in the customers collecting supplier real-time data that have a transparent supplier chain will be the ultimate expected outcome. This should result in more work being won by those customers with the more transparent supply chain and who are able to sell their supply chain management capabilities to end item users who want less risks in their procurements.

Behavior at the customer collecting the data is expected to change due to an increase in understanding of the combined impact of the customer on the supply chain due to the various actions taken by different programs within the same customer. Releasing orders late into the supply chain by various programs will be seen by feedback from suppliers as the suppliers' process data is seen by the customer. Behavior within the customer will also change for the supply chain professionals working there. No longer will the management of suppliers be based on individual relationships or a trust only. Trust but verification with data and information will be required. A complete understanding of which processes in the supply chain that impact delivery and quality the most for a given situation or supplier will be analyzed and resources placed optimally to improve those processes. A paradigm shift from writing a check and expecting the suppliers to manage themselves to a trust but verify system will require a more disciplined approach using Six Sigma and Lean tools. Fire fighting is the current method used to work with suppliers by customers. When an issue comes up, the customer sends resources towards solving the issue with no real root cause corrective action being done. A change to training in Six Sigma and process management will be needed for most supply chain professionals. Human resistance to change at a customer will be overcome by leadership expectations and value from the new real-time metric package and models using the data. Data analysis of suppliers' abilities in various situations will also be a change that is expected. Commodity group analysis by the customer to look for trends and leveraging opportunities will also result from the new metric package and model. Other expectations include a return on investment from reduction in delays and quality issues and increased sub-tier supplier insight using metrics that show how well a customer's supplier manages their own supply chain. Customers will also review what data they are collecting from suppliers and why. Metric collection correlation analysis to performance will allow the customer and supplier to optimize resources by not collecting and reviewing data that is not important.

Behavior at suppliers is expected to change due to the transparency their customers will have into their processes. Suppliers showed this during the initial data collection efforts in this dissertation. No longer will poor process control or capability be acceptable. Suppliers will need to be able to address their customer's concerns regarding their processes, not just the location or status of their parts in their shops. Another expected result is that suppliers will adjust to what is being managed and will perform their processes at a higher level and therefore will perform at a higher level overall resulting in improved delivery and quality from the customer.

A change in the relationship between the customer and supplier is expected due to the deployment of the supplier delivery prediction model. Trust by verify will be used by the customer collecting the data. A reduction in customer resources being sent to suppliers to fight fires should also occur due to increased confidence the customer will have in the supplier to do true root cause and corrective action knowing the customer will be able to see the results of the process changes well before a delivery issue is felt by the customer. Suppliers with great processes and great performance will be valued suppliers and provided additional opportunities from the customer collecting the data.

A change in relationships between members of the supply chain will also occur. When a supplier is impacting another member of the supply chain that supplies the same customer, the new real-time metric package will show this and allow for communication based on data to occur. In the past a supplier would not necessarily reveal when other suppliers were negatively impacting them. Good suppliers to the customer using today's metric packages may be seen as poor performers using the new metric package due to their negative impact on the supply chain. For suppliers that do not provide data into the new metric package, this lack of transparency will be held against them when teaming or sourcing occurs.

Behavior between the end item user and customer collecting the data from suppliers will change. End item users will place a value on the perceived and actual reduction in supply chain risk due to the increased supply transparency provided by the new real-time predictive metric package. This value will position the customer to win more work from the end user.

6.3 RISK MANAGEMENT

Overall the customer and supplier will be able to use each piece of the process information by itself to drive root cause and corrective action. The supplier delivery prediction model creates an overall supplier performance risk prediction model and corresponding actions that allows users to increase their use of standard work. Lean, Six Sigma, and continuous improvement tools are available to assist the customer and supplier to mitigate risks and resolve issues spot lighted using the real-time metric package and models. A benefit of using capability and stability analysis with the model is to not react to common cause variation in the performance of a supplier unless it makes the supplier not capable of meeting the requirements placed on it. Over reaction to common cause variation expends both customer and supplier resources with little to no return on the investment. Using data and the information derived from the data will increase the insight of both the customer and supplier into the risks and issues they face together. Collecting and displaying real-time data over time will improve their insight compared to the random snapshots of process information taken today if at all. Variation exists in all processes and now will be understood by both the customer and supplier. A properly targeted and predictable variation will allow the variation to be reduced if desired based on business decisions. In a world of supply chain surprises, this model will help reduce the number of surprises (Gordon, 2008). Using the data and information will allow both the customer and supplier to motivate, focus attention, clarify expectations, control, and reward efforts.

The management model in this dissertation took inputs that have been shown to be correlated with supplier performance from a test bed of suppliers and produced an overall risk rating and actions based on the overall risk rating. The model does not directly take into account past delivery and quality performance data captured by the customer. However, this data can be used as a check and balance to the outputs of the proposed model. Current delivery and quality performance of a supplier can also be used to validate the process data being collected along with the results of the model. The focus of the model is on the processes at the suppliers and for the daily management of a given supplier.

6.4 LIMITATIONS AND ASSUMPTIONS

The focus of the study in this dissertation is products for production programs and not research and development programs which use a different set of metrics including earned value. Leadership at the customer collecting the data specifically set the boundary of production suppliers only collecting production data.

Other limitations include the need to collect more metrics from the suppliers providing data, to collect more metrics from more suppliers, and to collect the data for a longer period of time. The results of the analysis are only as good as the data put into the analysis. More data would have possibly allowed for more significant metrics being found and better delivery prediction capability. Using existing metrics that could be collected from suppliers in a timely fashion and not all metrics possible was a requirement from the leadership at the customer. Future work at the customer will include collecting more metrics from suppliers and has already started. Another limitation was the inability to collect sub-tier information by the name of the sub-tier suppliers. Currently the customer has two projects trying to collect this data. Once collected, this data can be combined with the data collected in this dissertation to gain increased insight into the sub-tier of the customer.

Other approaches for this dissertation could have been to focus solely on the initial improvement of supplier performance to the customer collecting the data. This was not done because there were no active users of the data coming in from suppliers and therefore no change in behavior due to the collection of the data was expected. An ideal process to determine a suite of predictive metrics to be used by the new metric package would be to determine every risk and issue that a supplier or customer faces. Then determine the frequency of each risk and issue, the likelihood of a risk becoming an issue, and the consequences of each risk and issue, then to determine which metrics would have provided the best assistance for risk mitigation or issue solving. For a large scale customer with numerous individual programs, each of which controlling their own metrics, this is a difficult to impossible task.

A key assumption for the model the supplier’s performance was not impacted by the collection of the data by the customer and therefore normal operating conditions existed during the collection of the initial data to determine which metrics correlated to performance. If extra or non-normal action by the supplier would have been taken due to the customer collecting the data the correlation analysis would have been between on-time delivery and extra mitigation actions instead of the process metrics. Another assumption made and tested for was that the metrics collected from the suppliers was independent of the other metrics being collected. Fisher Test was used to locate these independences and were taken into account in the formation of the three data sets. Another assumption for the model is the integrity of the supplier to not modify their process data prior to sending it to the customer is critical. A clear expectation was given to the suppliers regarding the accuracy of the data and the fact the data was provided voluntarily leads to the assumption the data was accurate and not adjusted by the supplier. An assumption with the delivery data collected by the customer is that adjustments were not made to the delivery data to improve a supplier’s score for the reason that customer’s supply chain professionals have their performance reviews tied to their supplier’s performance on delivery. Another assumption is that each supplier is providing data that is consistent with the definitions of each metric as defined by the customer. An interface control document was used along with verbal instructions to ensure this. The interface control document contained specific and detailed definitions of each metric and each data element required to build the metric. An example of this would be the term late and how it applies to the supplier's data. If a purchase contract is not placed on time, is it counted late when it is not placed or is it counted late when it is placed 2 weeks later? Consistency in data was stressed to the suppliers; however, experience during the data collection period showed that metrics in general are not universally calculated.

The utility of the findings from the study area which was a customer during a production program to begin collecting supplier process metrics from suppliers who had not previously provided the requested metrics on an ongoing basis is a limitation due to the small set of data collected being extrapolated to a large group of production suppliers.

6.5 FUTURE WORK

The future work in the area of customer collected real-time metric packages and making predictions from them is critical to the success of supply chains. A barrier for a sustainable supply chain is insufficient communication in the supply chain (Seuring and Muller, 2008). The new real-time metric package concept will be a driving force in risk management and performance improvement for not only daily usage but also the future predictions. What gets managed gets improved. The supply chain will know the customer and potentially the end item user can see into the supply chain. This visibility will put a positive pressure on the supply chain to perform. Knowledge accumulation and sharing is critical to improving supply chain performance (Marra et al., 2012).

Further research will need to be done comparing companies who use different supply chain metric packages.

Future work in the area of customer collected supply chain predictive metric packages is almost limitless. Possible future areas of work include standard metric packages across industries, different metrics to be collected, predictions being made from the metrics being collected, and standard reactions to the collected metrics.

Future work in the area of establishing standard metric packages and collection systems within industries is needed. With increased business requirements between suppliers, customers, and end item users, the need for standard work is great for efficiencies and consistency. Total supply chain transparency with data driven decisions being made is critical as suppliers impact other suppliers who impact customers and end item users. As suppliers begin to demand more data from their own suppliers, the need for a common format of data exchange will drive standard work in the area of metric collection. Utilizing supply chain management organizations within industry will increase the likelihood of success in this area.

Future work in the area of which metrics to collect and to make predictions from is needed. With metrics being readily available, the ability to determine correlations to supplier performance for a customer is possible including examining metrics at the customer to increase prediction capabilities. An example of different types of metrics for collection is if a supplier is located in a region with a weather forecast of temperatures above normal for the next 3 months. Past supplier process data and supplier to customer performance data could show that the supplier has increased risks when the temperature rises above normal due to either more vacations being taken or a poor facility air conditioning system. Other possible key metrics to include in future supply chain metric package work includes customer provide data such as on-time purchase contract placement, changes to quantities or schedules for supplier delivery, on-time engineering release from the customer, and forecasted part quantity and schedule requirements. Supplier to customer quality metrics can also be a source of insight moving in the direction of predicting supplier quality performance. The metrics obtained in this dissertation did not include all possible metrics due to the leadership at the customer and their desire to not overwhelm their supply base with too large of an initial data request and the resources required to build a tool to capture and display a large set of metrics.

Future work in the area of collecting the total sourcing cost to source with a particular supplier or supply chain (Bhagwat, 2007) is also needed. Understanding the total cost will allow both customers and suppliers to make better make/buy decisions (Aksoy and Ozturk, 2011). Huang and Keskar (2007) believe the trend is shifting towards developing more exhaustive and detailed performance metrics to provide transparency for a supply chain and understanding the total costs of procurement are part of this transparency. Metrics tracking the amount of resources at a customer used to manage a supplier at different times and compared to other customer and supplier process data will provide insight into the total cost of procurement and allow for predictions in this area to help with resource allocation decisions.

Future research into the area of sub-tier management and metric packages is needed. Determining the supply chain maps for a customer is a critical first step to supply chain management. Collecting critical actionable data at various points along the supply chain will allow for better supply chain management and improved supply chain performance prediction capabilities. A standard metric package set and collection system will increase the likelihood of success in this area.

The idea of using such a test bed can be expanded to cover other non-traditional metrics including but not limited to: outdoor temperature at supplier (warmer could equate to less work done due to outside work activities), educational test scores for the school district the supplier is located in (higher test scores could show parents are not focused on their jobs and are working with their children more than other locations), number of doctors within 50 miles of the supplier (higher stress levels therefore more doctors therefore less work getting done), number of different customers for a supplier (more customers, less preferred customers), number of other businesses open and closing within 50 miles of a supplier (competition for workers, stress on families losing jobs, overall economic condition of the region). The use of qualitative metrics to understand sources and levels of risk is also needed (Lamber et al., 2001).

Future research is also needed in the area of measuring the relationship between a customer and its suppliers. Measuring this relationship along with other process data can help in creating transparency. A customer needs to understand when they are and are not a preferred customer. This knowledge will help customers resource efforts and plan for risk mitigation activities and continuous improvement projects. Other areas of future research that are needed in the area of metrics include does measuring a supplier strengthen or weaken the relationship between the two companies, do businesses like being measured by other companies, and how much should an end item user understand and value the relationships within the supply chain making a product for them. Future relationship metrics will be able to add meaning and clarification to the various process metrics being collected.

Future work in the area of making predictions using supply chain metrics is needed to improve risk identification and mitigation activities. Predictions using real-time metric packages can be used on contracts where the buyer receives discounts for committing to purchases in advance (Lian, 2009). Predictions about the performance of a supplier or supply chain under different quantities of orders can be used to negotiate a more favorable schedule and cost associated with that schedule.

7. CONCLUSIONS

Key pressures and incentives from improving the supply chain include legal demands, customer demands, improved response to stakeholders, and the need for a competitive advantage (Seuring and Muller, 2008). Forces transforming supply chain management include the increased dependence on the outsourcing of goods and services, globalization, supply management technology, time and market responsiveness, and performance improvement methodologies (Gordon, 2008). This transformation of the supply chain requires turning data into information that is actionable and is a key future work area and was started in this dissertation. Creating a supplier delivery prediction model based off metrics collected will allow supply chain professionals to better manage their supply bases. Using stability and capability analysis on the metrics collected will drive root cause corrective action in a simple to understand format based on common cause variation and special cause variation. Using a supplier delivery prediction model to create a supplier classification of low, medium, or high risk will add value to the supply chain professional and their leadership by allowing for resources to be focused on the suppliers that require attention. This research also provides recommended actions to take for the different levels of risk for a supplier. This standard work will allow for better communication within the customer and increase the efficiency of the customer's supply chain professionals.

7.1 RESULTS

These analysis allow for customers of supply chains to focus on which metrics to collect from suppliers, how to determine where to spend resources in the management of suppliers, and to gain an understanding if they are receiving a preferred customer status.

Scholtes (1998) states that things are measured for two reasons: to see how things are going and to predict the future. How is a supplier doing today and how will a supplier be doing in the future are both key areas for the supply chain professional and is a critical problem facing customers and suppliers today and is addressed by the work in this dissertation.

7.2 IMPLICATIONS

Many companies have not succeeded in maximizing their supply chain's potential because they have failed to develop the performance measures and metrics to fully integrate their supply chain. (Gunasekaran, 2006). Analytics is becoming more and more important in supply chain management. (Jain, 2009). The research in this dissertation accomplished many things including generating a list of key supply chain metrics, determining and using criteria to down select to 12 key metrics, collecting data from suppliers, calculating the correlation for the metrics collected to delivery to the customer, determining the prediction capability of each model, beginning the future work of a supplier delivery prediction model and supplier risk model, and starting the future work of developing the actions to take in the management of a supplier at various levels of risk.

7.3 WHAT'S NEXT

The future of real-time metric package prediction capabilities also includes no longer initially configuring or designing the supply chain assuming no failures (Kull, 2008). Data analysis and the predictions made will show all supply chains will fail at some level. Risk mitigation plans will be created based on the performance capabilities of the suppliers making up the supply chain and can be implemented in the earliest stages of the construction of the supply chain. Another area of future work is using a fuzzy framework and adjusting the autonomy within the supply chain to react to changes in the business environment (Lau, 2008). Tying the metric package into supplier selection models that include supplier location models can also be done as shown by Melo (2009). To predict the outcome of a supply chain before a single contract is placed would be a huge advancement in prediction capabilities in supply chain management. Trying to create a metric package like this is similar to predicting a baseball game's results prior to the first pitch being thrown. The future metric package and supply chain model would be similar to taking the battings averages of the players in a game, the game weather conditions and location, batting averages of hitters versus pitchers on the other team, batting averages that take into the specific situations projected for the game, projected managerial moves, and other data that could impact the outcome. The result will be similar to today's video games that play games of teams from different eras. Though the event does not take place, a realistic picture of the outcome and the events would be seen. Pareto-optimal supplier selections in a chance constrained programming model with various supplier inputs including real-time metrics can be used to predict the probability of not meeting a customer's demands (Li and Zabinsk, 2011).

Supply chains increased in importance in the 1980's as supplier usage increased to nearly 60% of the total product cost (Gunaskarna, 2004). Today the percent is as high as 100% on some products. With this increased importance of supply chains, new and improved ways of managing them is needed. Better insight into the supply chain is the preferred approach (Gordon, 2008). Traditional metric packages can now be supplemented with real-time proactive metric packages like the one created in this dissertation. Behavior changes are needed for efficient deployment of real-time metric packages. The deployment of the real-time metric package in this dissertation allowed for a metric analysis to be conducted to determine which metric correlated to supplier performance. The future of data collection from suppliers is critical to the success of companies.

The better a customer knows their suppliers, the good and bad points, the less likelihood of unpleasant surprises (Gordon, 2008). Specific supplier examples collected during this research showed that the developed metric package and models provided insight. They increased the insight of the supply chain professionals at the customer and increased the transparency of the supply chain by spot lighting processes that in the past no data was collected on by the customer. Improved root cause correction action and even improved relationships with suppliers by focusing discussions on the supplier's data and simple to understand concepts such as capability and stability of a process was seen using the supplier provided data allowed for discussions to take place that did not focus on how the customer was counting late delivery hits.

Patterson (2002) states that facts are critical to laying the groundwork for crucial conversations. The facts are needed in the discussions between suppliers and customers. Facts based on real-time process data not just past delivery and quality data. Davenport and Harris (2010) state that analytical competitors look beyond basic statistics. The quicker a company gets the information, the quicker they can make plans for the unexpected glitches in the supply chain. Optimizing the supply chain can only be done if the supply chain is transparent enough to see the risks, issues, and opportunities in it.

Davenport and Harris (2010) state that two thirds of the companies they surveyed believed they needed to improve their company's analytical capabilities while 72% indicated they were actively working to increase their ability to work analytically. These increases in analytical capabilities will be readily seen in supply chain management. As data becomes more available, the transformation of the data into information will be critical for this growing field. As the supply chain competes with a company's own ability to make a product, the analytical capabilities of supply chain management will be critical to show that it is a good business decision to outsource products. Internal manufacturing groups will point to the loss of control and increased risks in using supply chains. It is up to the analytical capabilities of supplier management professionals to show the risk can be management and that controls are put in place. The supplier management professional's job and career is riding on their ability to become more analytical.

Trent (2010) states that supplier performance measurement includes the methods and systems to collect information to measure, rate, or rank suppliers on a continuous basis. The new metric package will manage the supply chain in a similar way that the customer uses to manage their production facilities or how a general manager would manage at a supplier today. This level of insight and transparency is needed today. Covey (2006) says transparency is about being open, real and genuine and telling the truth in a way people can verify and says the opposite of transparency is to hide, cover, obscure, or make dark while the counterfeit of transparency is illusion. Though Covey is talking about relationships between people, aren't customers and suppliers made of people? Don't the same ideas apply?

Key focus areas from improvement to supply chain management have been analyzed and information technology and human resources have been targeted as major drivers for improving the total level of supply chain management execution (Teller, C. et al., 2011). This dissertation uses information technology in the collection and presenting of real-time supplier process metrics and accounts for human resources by presenting standard work and the need for training in the areas of statistical control processes for supply chain professionals.

Overall the future of measurement for supplier management will be as varied and complex as the supply chains they are trying to create and manage. Moving to an environment where supply chain professionals are given credit for mitigation of risks, solving a problem or issue before it occurs, will also drive the need for more measurements within the supply chain. Supplier performance management is the process of evaluating, measuring, and monitoring supplier performance and suppliers’ business processes and practices with the goal of reducing costs, mitigating risks, and causing continuous improvement (Gordon, 2008). The work in this dissertation attempts to help in each of these areas.

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VITA

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